Guidance for Flood Risk Analysis and Mapping

Mapping Base Flood Elevations on Flood Insurance Rate Maps

November 2023

FEMA

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Requirements for the FEMA Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at https://www.fema.gov/resource-document-library.

Table of Revisions

The following summary of changes details revisions to this document subsequent to its most recent version in November 2022.

Affected Section or Subsection	Date	Description
1	Nov. 2023	Updated description of Automated Map Production (AMP).
2	Nov. 2023	Narrative and Figure 3 added to clarify when additional BFE lines may be necessary to accurately estimate water surface elevations in a 2D modeled area.
4	Nov. 2023	Titles added for Subsections 4.1 and 4.2 to differentiate specific guidance for 1D and 2D models, respectively. Section 4.2 was previously Section 5.
5.4	Nov. 2023	Added clarification regarding riverine zones controlled by coastal backwater.
All sections	Nov. 2023	Various minor style updates or phrasing adjustments for improved clarity.

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1. Automated Map Production

To support greater automation within the Risk MAP Program, FEMA has developed a tool within the Mapping Information Platform (MIP) called Automated Map Production (AMP). AMP automates Flood Insurance Rate Map (FIRM) panel creation, replacing previous practices of manual cartography. The goal of AMP is to eliminate the need for manual edits or adjustments to labels on the FIRM panels and FIRM index.

AMP reads the data in a submitted FIRM database and uses a series of cartographic algorithms, with established rules of hierarchy, to autogenerate FIRM panels and indexes that comply with FEMA requirements through all study stages (e.g., draft, preliminary, and final). However, AMP does not change the engineering analysis, alter the FIRM database (i.e., geodatabase; shapefiles) or generate the profile. AMP does not fix errors in the submitted FIRM database (e.g., topology). It will continue to be the responsibility of the FIRM database producer to perform quality assurance / quality control (QA/QC) to make sure the submitted data meets all Risk MAP standards. Producers are expected to visually review the auto-generated AMP panels to determine if they meet expectations or require changes. If updates are needed, the producer is expected to edit the FIRM database and then resubmit it to the MIP as usual, to begin the process over, to include required Database Verification Tool (DVT) submittals.

Producers need to understand how AMP impacts the guidance in this and other Risk MAP guidance documents. While the mission of AMP is to replicate the FIRM panel and FIRM index requirements as known today, there are slight changes to the output panels that do not directly align with other published FEMA guidance. AMP panels have slight variations from what producers and users have seen since the beginning of Risk MAP. FEMA has developed a best practices document available here:

https://hazards.fema.gov/femaportal/usercare/guidesAndDocs/Documents/AMP_Best_Practices.pdf.

Because AMP will be enhanced through future agile development cycles, changes will likely occur more frequently than the annual Guidelines and Standards (G&S) cycle. Therefore, the best practice model will be the most efficient way to provide up-to-date information on changes. Future edits to this document will be made to align the information between this and the AMP Best Practices document.

2. Background

Water surface elevations of the 1-percent-annual-chance (base) flood are called Base Flood Elevations (BFEs). These BFEs may be designated on the FIRM using specific BFE lines (as done historically) or at one-dimensional (1D) model cross sections and/or two-dimensional (2D) model evaluation lines with the appropriate elevation labels. BFEs are placed on the FIRM to assist users in determining the elevation of the 1-percent-annual-chance flood elevation anywhere within the floodplain. For more detailed information on BFE determinations, users should reference the base flood profile in the Flood Insurance Study report, where applicable.

For the purpose of this guidance document, the term BFE refers to:

- The 1-percent-annual-chance water surface elevation shown on 1D cross section lines, as noted in the FIRM Database S_XS feature class <WSEL_REG> field and at mapped cross-sections on the FIRM as demonstrated at Cross Section L in Figure 1, or,

- The 1-percent-annual-chance water surface elevation shown on specific BFE lines (often used to supplement 1D cross section or 2D evaluation line values) as noted in the FIRM Database S_BFE feature class <ELEV> field and on the FIRM as demonstrated by elevation 462.2 in Figure 1. BFE lines may be shown as whole foot rounded values or to the 10th of a foot (decimal), depending on stream slope and map scale. See Section 3 for more information on the use of decimal BFEs vs. whole-foot rounded elevations.

- The 1-percent-annual-chance water surface elevations shown on 2D model evaluation lines, shown on the FIRM if a floodway is calculated for a 2D or hybrid 1D, 2D models.

BFE lines (such as shown in Figure 1 for elevation 462.2) will be placed along the profile baseline (where applicable) at inflection points not already captured by 1D cross sections/2D evaluation lines, or as needed in areas of backwater, ponding, complex flow areas, overflow areas off the profile baseline, at node areas of Interconnected Channel and Pond Routing (ICPR) and similar models in very flat areas of Florida, or other areas needed per engineering judgment.

In a 2D modeled floodplain, water surface elevations along the profile baseline may vary significantly from nearby areas. As shown in Figure 3, BFE lines will be placed in areas where water surface elevations would be inaccurately estimated from the profile.

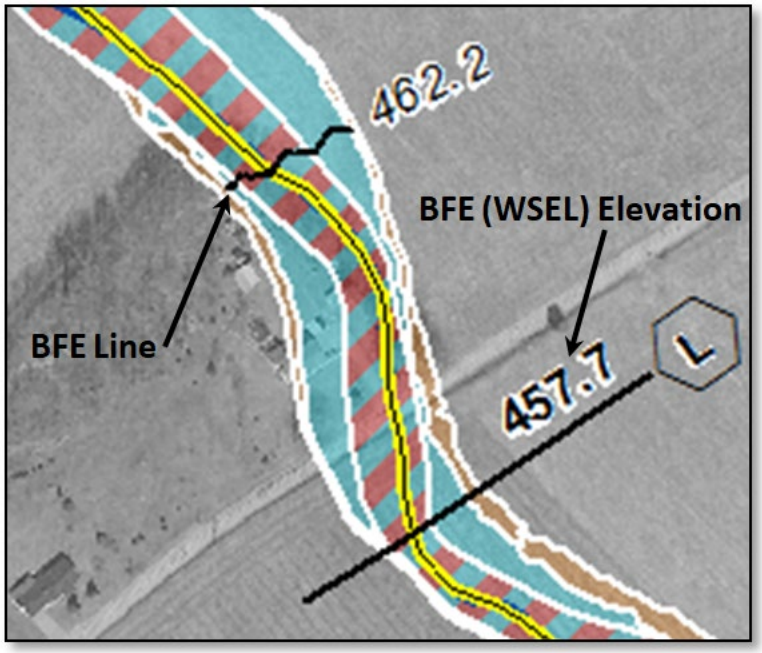

Figure 1: Two BFE Depictions on a FIRM with Cross Sections

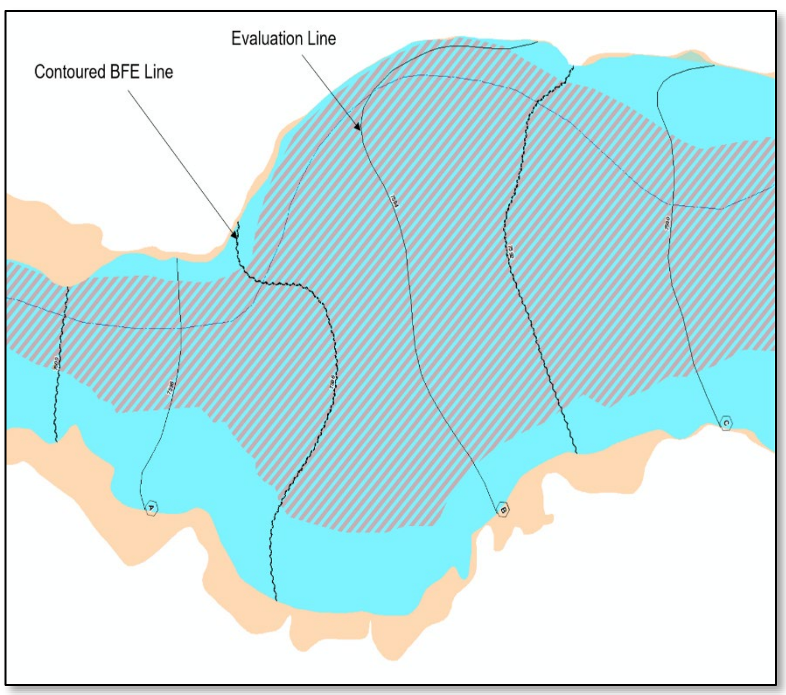

Figure 2: Two BFE Depictions on a FIRM with Evaluation Lines

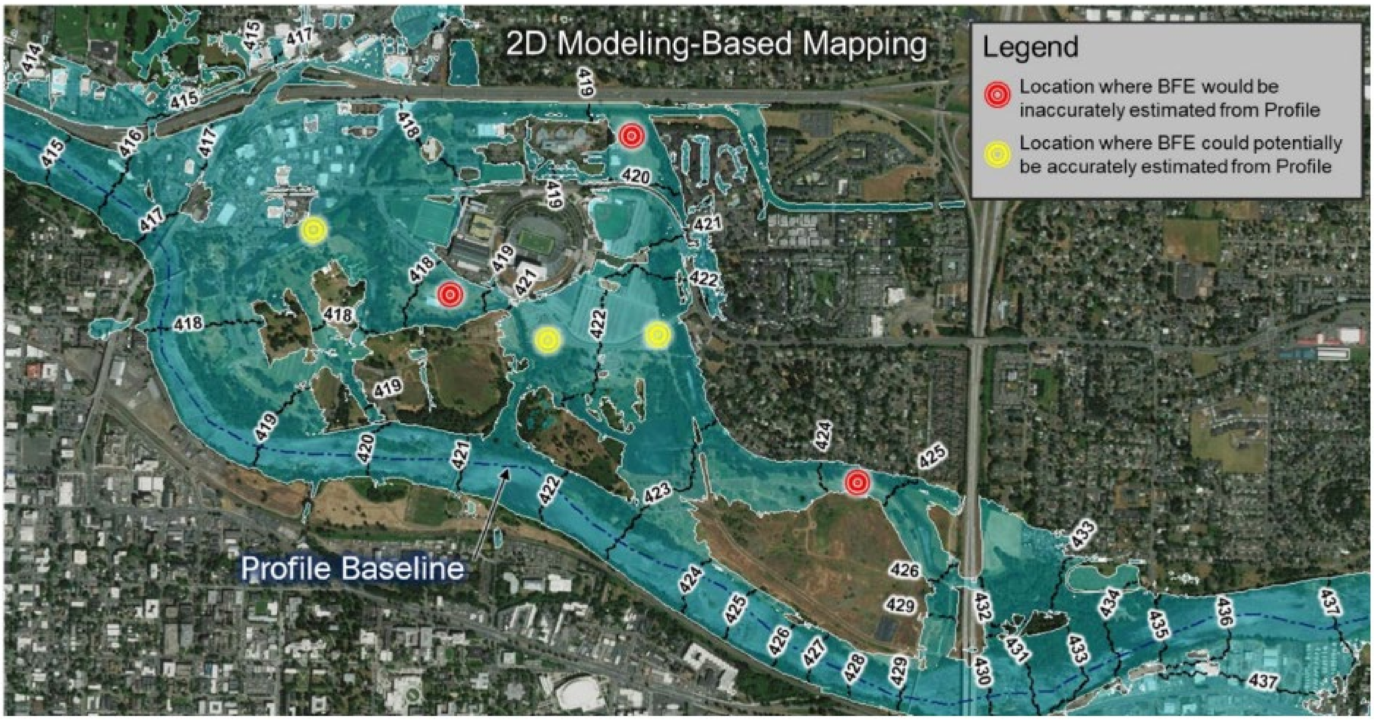

Figure 3: A 2D Modeled Floodplain in which BFE Lines Depict Water Surface Elevations in Areas Not Represented by the Flood Profile

FEMA Risk MAP standards require that BFEs (i.e., 1D cross section or 2D evaluation line values, supplemented with BFE lines where needed) must be shown at appropriate locations to allow map users to accurately interpolate flood elevations, both horizontally and vertically.

Because this requirement is results focused, there are no specific or prescriptive requirements associated with BFE value spacing or flood elevation rise between BFEs. The intent is that map users can accurately interpret flood elevations on the FIRM and that BFEs are placed strategically and at reasonable intervals to enable this intent. See Section 4 of this guidance document for more information on 1D cross section or 2D evaluation line placement relative to the plotting of BFEs on the FIRM. Figure 2 shows an example of BFE lines on a FIRM in conjunction with evaluation lines.

The remainder of this document is devoted to providing guidance on the use of decimal BFEs vs. whole-foot rounded elevations; cross section and evaluation line considerations; examples; and guidance that enables FEMA Standard ID (SID) 374 to be reasonably met. This includes examples of poor BFE mapping for context, backwater BFEs, converting effective unrevised BFEs (riverine, ponding and lacustrine) to 10th-of-a-foot (decimal) values; and coastal BFEs.

3. Use of Whole-Foot Rounded BFEs vs. Decimal Value BFEs

While FEMA standards allow for the use of decimal BFEs to supplement 1D cross section or 2D evaluation line BFEs, a few considerations must be accounted for in this decision. The first and most important consideration is relative accuracy. The question that needs to be answered is whether the hydraulic data supports the implied accuracy of plotting BFEs to the 10th of a foot. To help answer this question, it is recommended that mappers read Technical Paper 114 from the U.S. Army Corps of Engineers (USACE). This resource addresses multiple uncertainties, as well as methods to test the accuracy of Flood Profiles using such techniques as a Monte Carlo Analysis.

https://www.hec.usace.army.mil/publications/TechnicalPapers/TP-114.pdf

If decimal BFEs are used to supplement whole foot BFEs on the FIRM, they may be used in any sequence (0.5 foot, 0.2 foot, or 0.1 foot), as determined by the appropriate accuracy needed to replicate the flood profiles using reasonable intervals of BFE lines and BFE-labeled cross sections or evaluation lines on the FIRM. These sequences will be dictated by the stream slope and map scale; they may vary from stream to stream, and even along a stream reach.

4. Cross Section, Evaluation Line, and BFE Considerations

Because cross sections from the hydraulic model are now used as the primary flood elevation communication tool for 1D model results on the FIRM, it is critical that mappers understand the importance of cross section placement and alignment, or the placement of evaluation lines for 2D modeling. In situations where there are no traditional BFE lines, the location and alignment of cross sections or evaluation lines (if a floodway analysis is completed) becomes critical for proper interpretation of flood elevations and must be double-checked after the modeling is completed. Adding more cross sections, evaluation lines, or supplemental BFE lines may be needed. Having adequate BFE documentation on the FIRM is critical to determining flood elevations– especially at the fringes of the floodplains.

4.1 Cross Section and BFE Considerations for 1D Models

When cross sections are not sufficient to enable proper interpretation of flood elevations, they must be supplemented with BFE lines (either as whole-foot rounded elevations or decimal BFEs, depending on data confidence, as noted in Section 3 of this guidance document). In general, BFE lines are shown on the FIRM, by modelers experienced in hydraulic floodplain analyses, using the model results (output), the profile, the Digital Elevation Model (DEM) topography, and familiarity with the floodplain and hydraulic conditions. They use their experience and expertise to map supplemental BFEs (whether by using BFE lines to supplement cross sections or decimal BFEs as noted above).

The important thing to note, for 1D steady flow models, is that cross section orientation in the outer portions of the cross sections, where very little flow conveyance is found, are not significant in determining the base flood profile, as long as the profile, cross section, topographic data, and engineering judgment are used to plot the BFEs.

4.2 Evaluation Lines and BFE Considerations for 2D Models

Where a new or revised study is completed using a 2D or hybrid 1D-2D hydraulic model, cross sections are either not available or may only extend across the channel area and not across the entire floodplain. To accurately depict the water surface elevation grid generated by the 2D or hybrid 2D model, a combination of evaluation lines (if a floodway analysis is completed) and supplemental BFEs lines should be used on the FIRM. Note that evaluation lines may be based on BFE lines, but they may also take an alternate form, based on the study approach.

Water surface elevation grids generated from 2D models capture variations in the flood water surface along and across the stream profile. They therefore offer valuable information on overbank flooding and water surface variation. As such, these grids should be the primary source of data for BFE plotting based on the results of a 2D model, with BFE lines generated by contouring the water surface elevation grid at the necessary vertical spacing for BFE interpretation from the FIRM.

Where BFEs and evaluation lines are the primary source of water surface elevation information on the FIRM, the Mapping Partner should confirm that the lines placed are sufficient. They should allow users to linearly interpolate the BFE at any point in the floodplain within 0.1 foot of the true value from the model water surface elevation grid. This can be done by comparing a water surface elevation grid generated from evaluation lines and BFEs mapped on the FIRM to the water surface elevation grid output from the model. Where differences exceed 0.1 foot, additional BFE lines should be placed at the required vertical interval (not to exceed a 0.1-foot resolution) to reduce the difference. Due to spatial constraints and/or a steep slope in the water surface profile, it will not be possible to provide the required detail using BFE and evaluation lines on the FIRM panel in some situations. In this case, especially if the water surface profile between the mapped BFE lines/elevation lines is not linear, insets to the Flood Insurance Study (FIS) Report should be included to provide the required detail for the product user.

Figure 4 provides an example of the process a Mapping Partner might use to place BFEs initially at whole-foot intervals (step 1), and then add decimal BFEs at variously spaced locations to provide a better interpolation of the BFEs across the floodplain (step 2). If a floodway was being mapped in this area, some or all of these BFE lines might be used as evaluation lines for additional reporting. The Floodway Analysis and Mapping guidance document provides additional information on the use and selection of evaluation lines. The FIRM Database guidance document provides additional information on how 2D floodway evaluation lines are attributed and stored within the FIRM database.

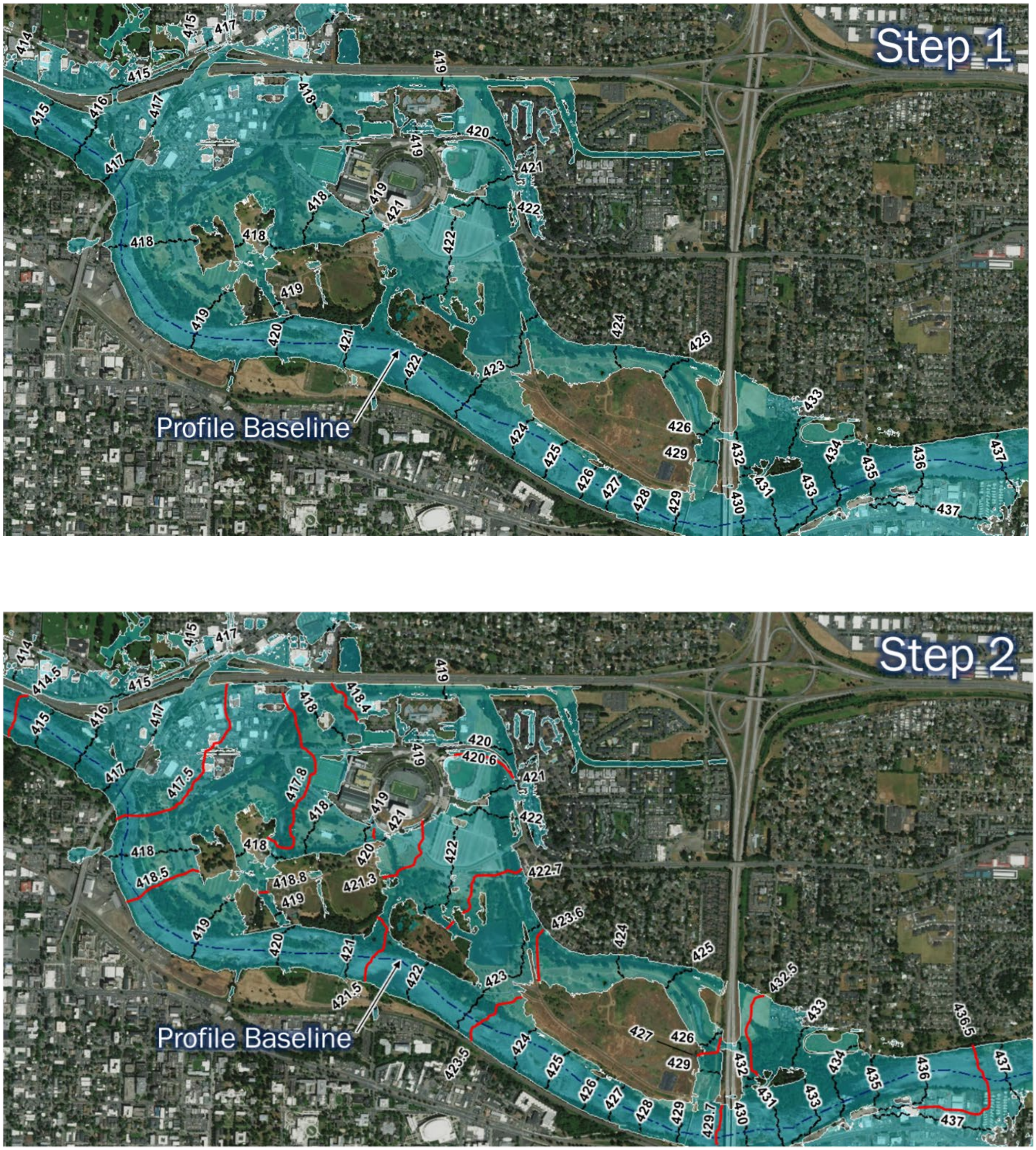

Figure 4: Sample Whole-foot and Decimal (Red) BFE Placement within a 2D Modeled Area

5. BFE Plotting

As implied in the FEMA standard, the goal of BFE plotting is to enable the map user to make an accurate flood elevation determination. To enable this standard to be met, it is important to note that applying a rules-based mapping protocol or a one-size-fits-all approach may yield undesirable results. As such, Mapping Partners must evaluate the map scale, stream slope and proximity to development when determining the best approach for plotting BFEs on the FIRM. BFE lines should be placed only “where needed” for new or revised riverine floodplains based on a 1D model, and to an appropriate level of precision based on the stream slope and map scale. For 2D model-based floodplains, BFE lines will need to be placed at appropriate intervals to comply with SID 128.

5.1 Plotting BFEs on New or Revised Riverine Study

For new and revised riverine flood elevations, BFE lines should be placed both horizontally and vertically to enable an accurate interpretation of the water surface elevations. Those BFEs should be expressed either in a decimal-place sequence (0.5 foot, 0.2 foot, or 0.1 foot) or as whole-foot rounded values. In areas of gentle stream slope, BFEs may be best expressed as 10th-of-a-foot values. In areas of significant stream slope, they may be best expressed as whole-foot rounded values. Determine the appropriate accuracy that is needed to replicate the flood profiles for 1D hydraulic analyses or water surface elevation grids for 2D analyses.

Where possible, if accuracy and map scale allow, it is recommended that all BFEs for an individual flooding source follow the same protocol. There are limited exceptions. Many streams will tolerate whole-foot BFEs near the mouth, where stream slopes are mild. Using the same whole-foot interval upstream, where slopes are steep, can create more confusion for map users than changing the sequence of the BFE lines. Some flexibility in applying BFEs may be necessary along a single stream, depending on slope and stream characteristics.

There is one notable exception (see Figure 5). For backwater arms, use whole-foot rounded values if you do not have sufficient confidence in the true backwater elevations. Likewise, if a flooding source does not support the accuracy implied by showing BFEs to a certain sequence (i.e., 0.5 foot, 0.2 foot, or 0.1 foot) due to map scale or stream slope, it is recommended to show all BFEs for the flooding source as whole-foot rounded values, without a decimal (i.e., 423, not 423.0).

Following this approach will enable the FIRM to represent the level of precision supported by the mapping and associated data. All new studies must map BFEs (whether on cross sections, evaluation lines, or “supplemental BFEs”) at their true location. Therefore, selecting the cross sections or evaluation lines to label the FIRM is critical to properly represent BFE data. A correct selection of cross sections should suffice in most straightforward 1D riverine situations.

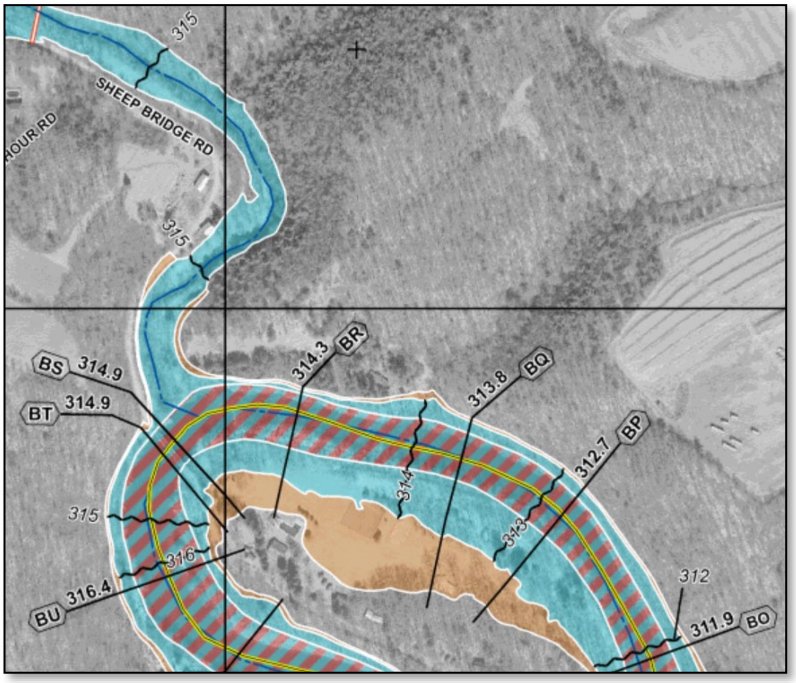

Figure 5: Area of Rounded Backwater BFEs

5.1.1. OTHER CONSIDERATIONS

The following are additional considerations for riverine BFEs:

- Streams that are being redelineated based only on new terrain data are not considered to have new or revised flood elevations.
- Showing flood elevations on backwater tributaries in a sequence (0.5 foot, 0.2 foot, or 0.1 foot) is optional. It is determined by the appropriate accuracy needed to replicate the flood profiles and based on the relative accuracy of expressing the backwater elevation to the 10th of a foot value. The relative accuracy will depend on the accuracy of the available topographic data, profile and map scale, and stream slope. If there is not sufficient confidence in representing the backwater elevation to the 10th of a foot, the backwater BFE should be shown as a whole-foot rounded elevation.
- For floodplain segments that are not large enough to graphically “carry” a BFE line, the BFE label should only be shown to the 10th of a foot if there is sufficient confidence in the flood elevation at that location. Otherwise, it should be shown as a whole-foot, rounded elevation.

5.2 Plotting BFEs in Areas of Complex Overbank Flow

Figure 5 displays an area of complex overbank flow in a 1D model. This area would benefit from additional BFEs, “bent” using available terrain data and engineering judgment, to reflect flow patterns in overbank areas. This would enable a more accurate representation of flood elevations at all points within the floodplain. These BFEs must traverse the entire floodplain to reflect the consistent 1-percent-annual-chance water surface elevation (WSEL) in the overbank areas, with the BFEs drawn perpendicular to the flow path. Take care to depict these BFEs in a way that enhances the clarity of the changing water surface elevations in relation to other features on the FIRM. Evaluate the placement and orientation of cross sections and the use of BFEs to ensure that they accurately and clearly convey the water surface elevations.

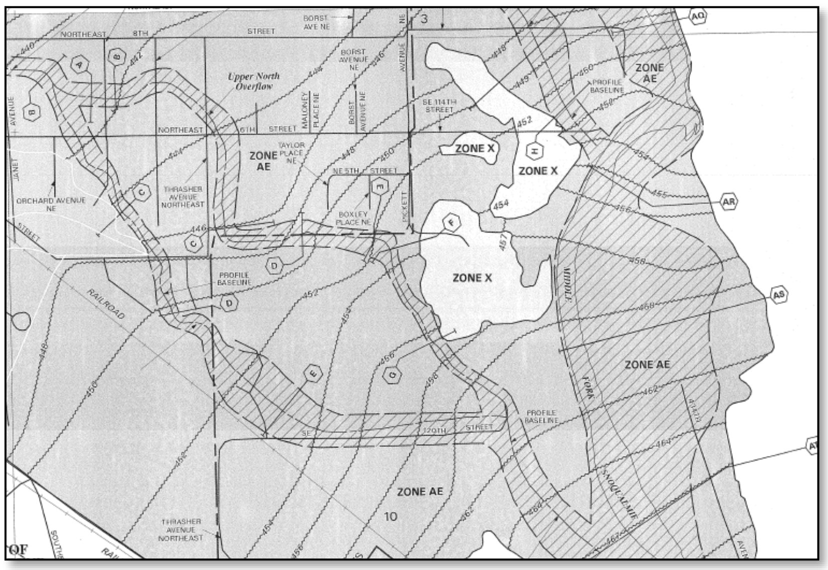

Figure 6: Area of Complex Overbank Flow Patterns

Where complex overbank flooding is evaluated by a 2D hydraulic analysis, follow the guidance outlined in Section 5 to accurately represent the modeled water surface elevation grid. If the BFE plotting is adequate by a 2D hydraulic analysis, the BFEs determined by linearly interpolating between the nearest BFEs should be within 0.1 foot of the BFEs determined from WSEL grids. This can be checked by using sample points.

In the example shown in Figure 7, the WSEL at the red dot is 2279.3 feet North American Vertical Datum of 1988 (NAVD 88) per the WSEL grid. Linear interpolation between the two nearest BFE lines, 2278 feet and 2282 feet, results in an elevation of 2279.4 feet. This is a reasonable approximation of the WSEL grid, so the spacing is adequate in that area. Automated methods may be used to get numerous test points in the area to determine that the BFE spacing is adequate.

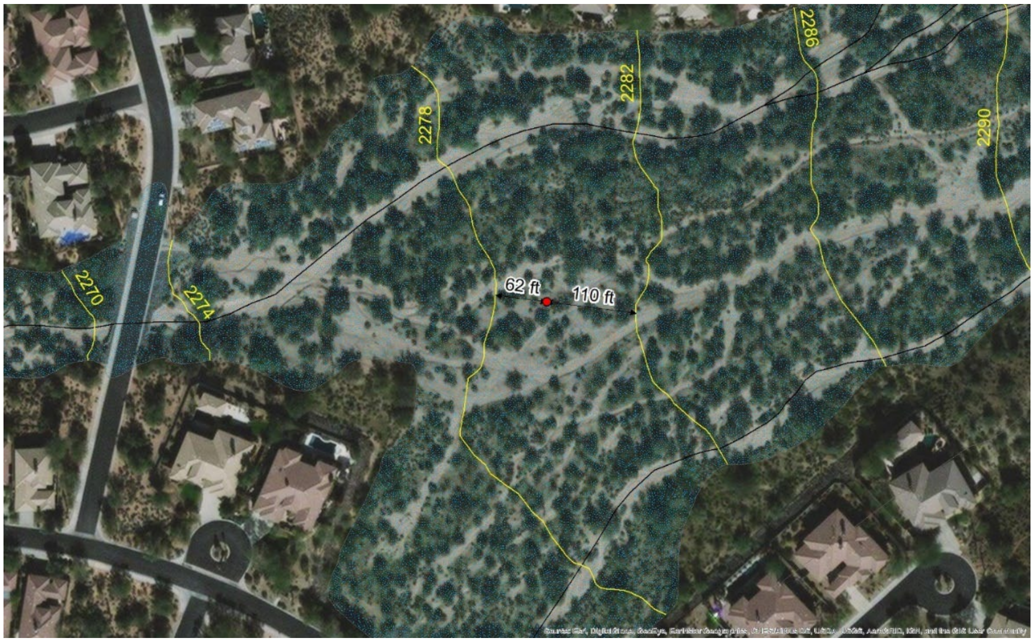

Figure 7: BFE Plotting Check for 2D Hydraulic Analysis

In Figure 8, the WSEL of point A is 417.7 feet (NAVD 88) per the WSEL grid. A linear interpolation between the two nearest BFE lines, 417 feet and 418 feet, estimates an elevation of 417.5 feet. Similarly, the WSEL grid indicates that the WSEL at point B is 422.6 feet (NAVD 88). A linear interpolation between the two nearest BFE lines, 422 feet and 423 feet, estimates an elevation of 422.3 feet. Since the difference between the linear interpolation and the WSEL grids is more than 0.1 foot, additional BFE lines are necessary in this area.

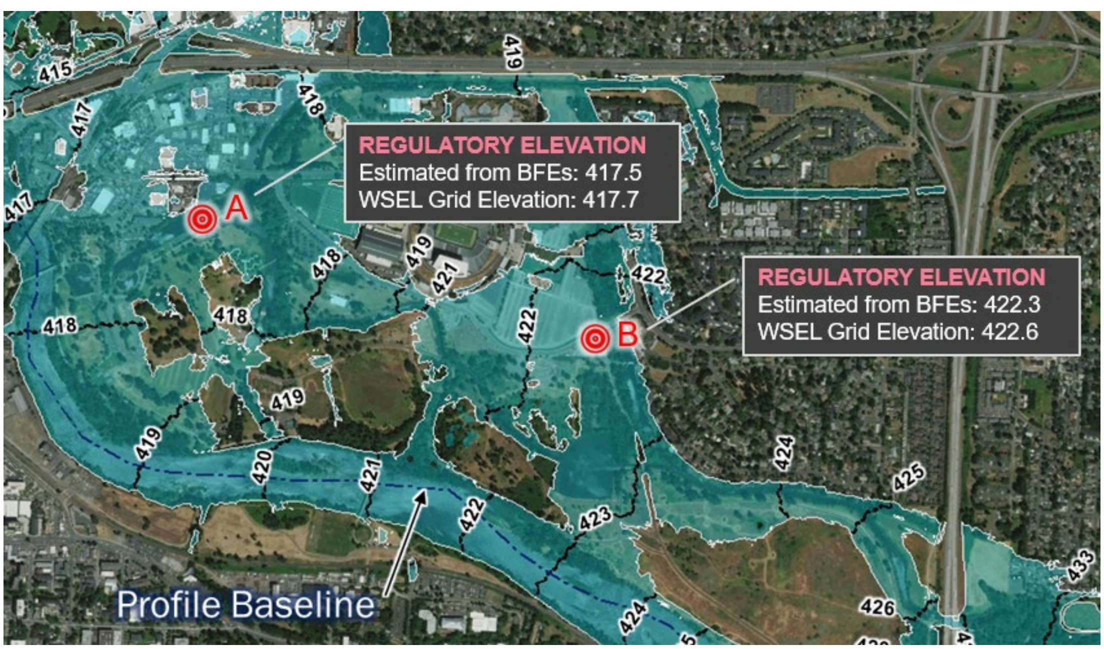

Figure 8: Whole-foot BFEs

Figure 9 shows the use of “spacer” BFEs (ex: start with 0.5 foot) generated from WSEL grids, where needed. Figure 10 compares the BFE estimation after adding the “spacer” BFEs; this results in adequate BFE plotting.

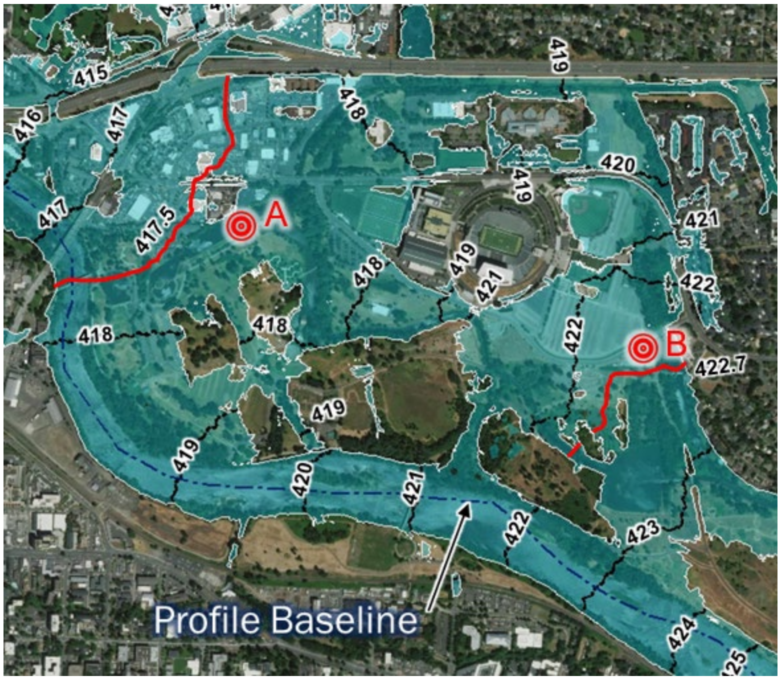

Figure 9: Addition of 0.5 foot “Spacer” BFEs

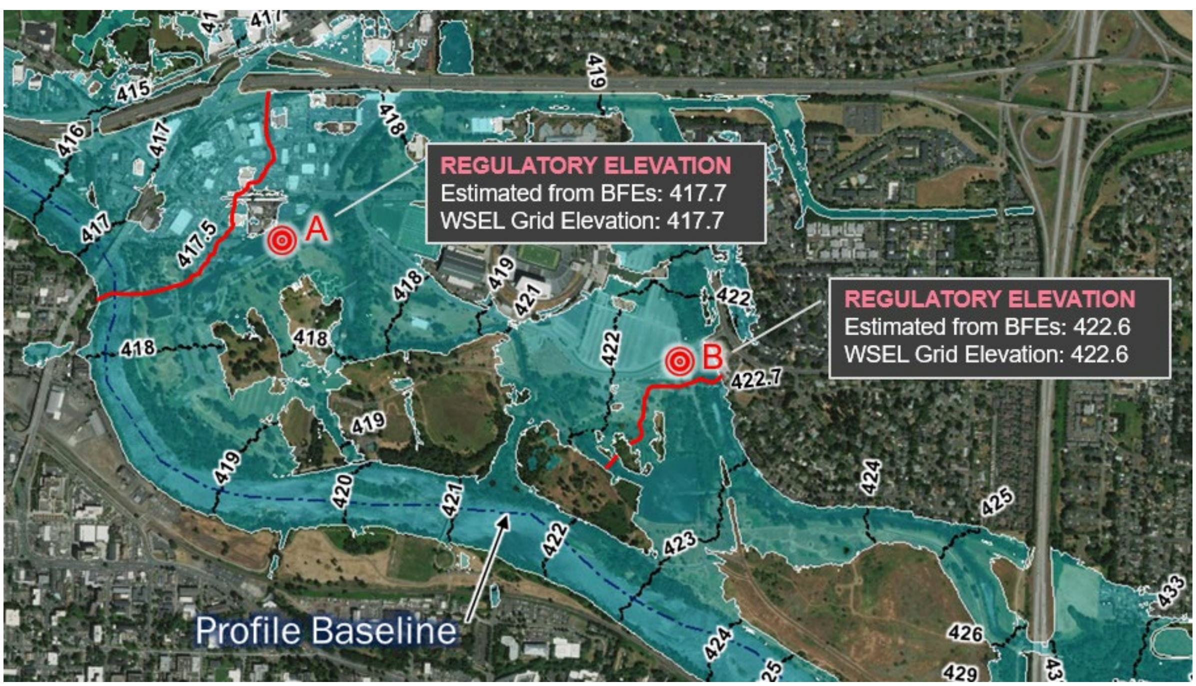

Figure 10: BFE Comparison After Using the “Spacer” BFEs

5.3 Avoiding Overcrowding of BFEs

FEMA standards on BFE plotting were focused on a specific allowable rise between BFEs and the stream gradient. While these are important considerations, note that mandating (for example) a 1-foot maximum rise between plotted BFEs could result in overcrowding on the FIRM. This is demonstrated in Figure 11. An extreme crowding effect was caused by placing BFEs at every whole foot in an area of significant stream slope. Figure 12 demonstrates an area of regular stream slope, which has enough cross sections to represent flood elevations but also several unnecessary BFE lines. Those were placed to meet the prior standard of showing whole-foot BFEs at every foot of vertical rise. In some 2D areas, it is not possible to provide adequate detail using BFE and evaluation lines on the FIRM panel, due to spatial constraints or steep or non-linear water surface profiles. Include inserts to the FIS report to provide the detail needed for a BFE determination in these areas.

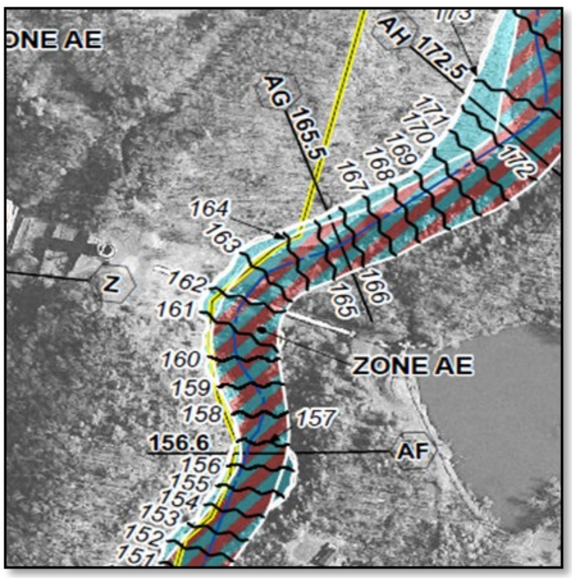

Figure 11: BFEs Plotted at Every Whole Foot on a Stream with Significant Slope

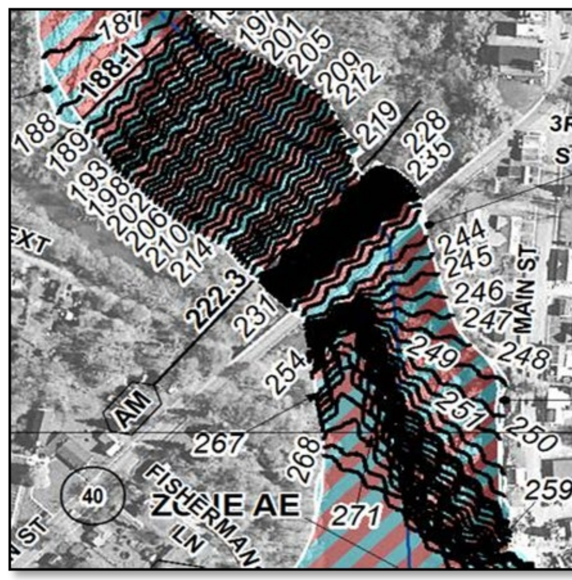

Figure 12: Several Unnecessary Whole-Foot Elevations

5.4 Ponding, Lacustrine, and Coastal BFEs

SID 106 requires that BFEs for ponding and lacustrine areas be expressed to the 10th of a foot if they have been calculated to that level of precision. Otherwise, they should be shown as whole-foot rounded elevations. Unrevised lake and ponding elevations may be converted to 10th-of-a-foot elevations, if this is supported by technical data, on a project-by-project basis, in coordination with the FEMA Project Officer. BFEs for coastal flood zones must be shown as whole-foot elevations.

Care must be taken in the decision to convert unrevised ponding and lake elevations. If the hydraulic analysis used to derive the elevations on the prior FIRM supports this level of precision and a conversion of this sort, the Mapping Partner may proceed. When there is doubt, it is recommended that the Mapping Partner consult the FEMA Project Officer.

5.4.1 COASTAL BFES

Coastal BFEs will be shown as whole-foot rounded values for new studies. Unrevised coastal flood elevations will normally not be updated to 10th-of-a-foot values. Specific exceptions may be granted through coordination with the FEMA Project Officer and via the FEMA Guidelines and Standards Exceptions Process. In areas of riverine influence controlled by coastal backwater, coastal BFEs will be mapped on the FIRM and riverine 1D cross section BFEs will be represented with the appropriate null value in the FIRM database.

5.5 BFEs for Unrevised Flooding Sources

Unrevised BFE lines may be converted to 10th-of-a-foot values as a project-specific option, based on regional discretion. For example, if 90 percent of the streams are being revised, the region may decide to convert the remaining BFEs to 10th-of-a-foot values, if this level of precision is determined to be warranted and justifiable.

Before converting unrevised BFEs, determine whether accurate flood elevations can be derived from the FIRM. For example, if the flood elevations are not attributes of the profile baseline (i.e., older studies) and the Flood Profile is shown at a vertical scale of 1 inch = 20 feet, it may not be possible or reasonable to convert the unrevised flood elevations with a high degree of accuracy. The test for this would be that the accuracy of the converted BFEs should enable the Flood Profile to be re-created to within ½ foot at any location. For many unrevised flooding sources, the addition of more BFE lines may be needed to meet this requirement.

Effective (unrevised) lake elevations may be shown to the 10th of a foot only if supported by a Summary of Stillwater Elevations table in the FIS report (and as noted earlier) the hydraulic analysis used for the prior FIRM.

Figure 13 demonstrates how an unrevised stream with BFEs converted from whole-foot rounded values to the 10th of a foot value may appear.

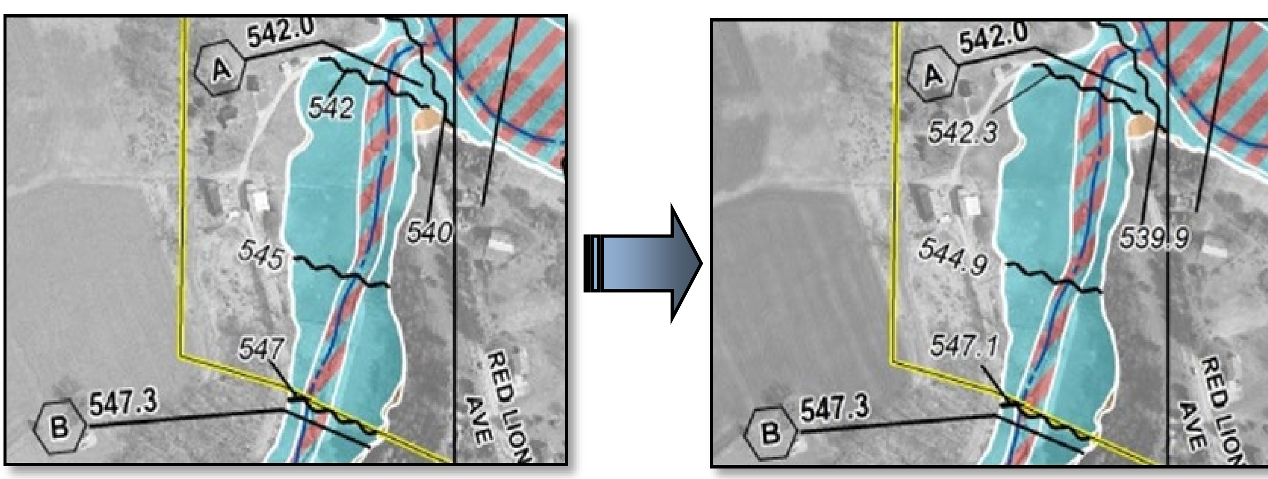

Figure 13: Unrevised BFEs

Unrevised BFE lines may, at regional discretion, be converted to 10th-of- a-foot values if the stream slope and map scale are determined to enable an accurate interpretation of the effective flood elevations. When deciding whether to convert unrevised flood elevations to the 10th-of-a-foot value, consider the following factors:

- Cost: How many flooding sources (and stream miles) on the FIRM panels being revised contain unrevised BFEs?
- Consistency: Would it minimize end user confusion to have all BFEs on a FIRM use a consistent sequence (0.5, 0.2, or 0.1 foot)? This sequence would be based on the accuracy needed to replicate the flood profiles. If 90 percent of the streams on a FIRM are being revised, it may be worth converting the unrevised flood elevations as well. Note: Since the accuracy of the BFE information on the FIRM depends on stream slope and map scale, converting the BFEs for all streams to this standard may not be reasonable or realistic.
- Accuracy: What is the perceived or relative accuracy of the conversion? If the flood elevations are not attributes of the profile baseline (i.e., older studies) and the Flood Profile is shown at a vertical scale of 1 inch = 20 feet, it may not be possible to convert the unrevised flood elevations with a high degree of accuracy.

Regions will need to make individual decisions on the conversion of unrevised flood elevations, based on the perceived value of doing so and the actual benefit to map users.